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Getting to know the secrets of EUV lithography

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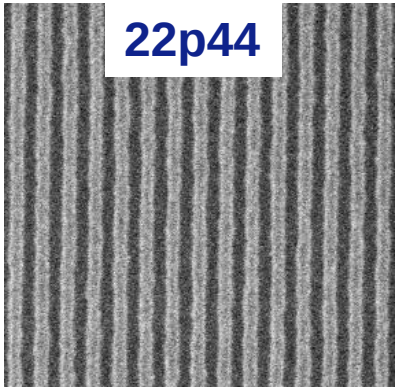
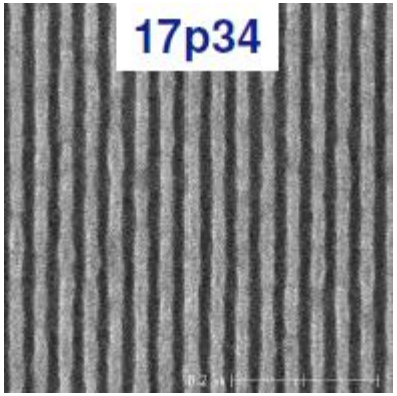
EUV lithography towards production

NXE:3100

- NXE:3100 (NA=0.25, 27 nm) – 6 systems in customer fabs
  - Printing wafers for device development
- NXE:3300B (NA=0.33, 22 nm)
  - First light – June 2012
  - Showing 22 nm imaging and below





August'12

NXE:3300B

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Outline

- NXE:3100 budget breakdown and learning
  - Mask contribution
  - Local CDU
- NXE:3300B – Early integration results
- Summary and conclusions

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Outline

- **NXE:3100 budget breakdown and learning**
  - *Mask contribution*
  - *Local CDU*
- *NXE:3300 – Early integration results*
- *Summary and conclusions*

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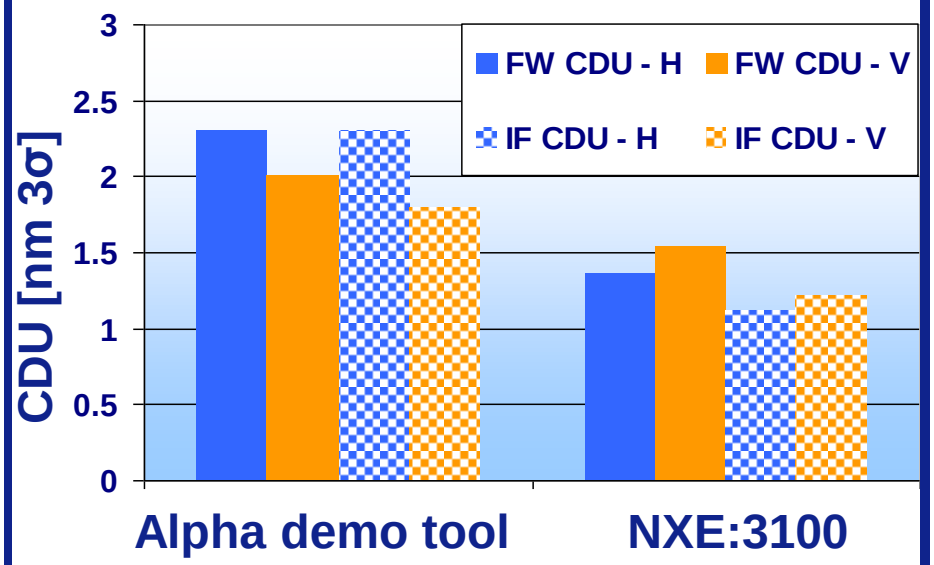
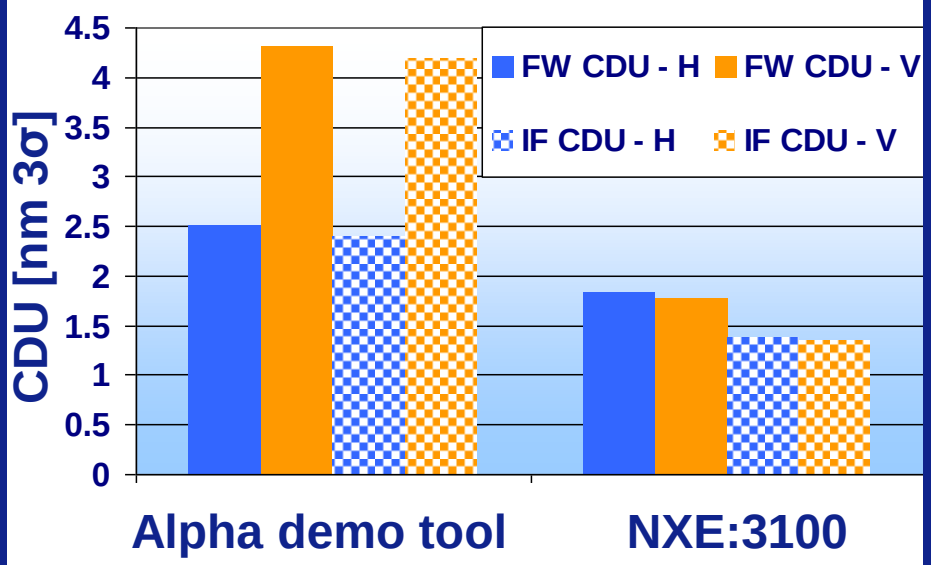
Full wafer and intra field CDU on NXE:3100: 27nm dense lines < 1.5nm 3σ 27nm iso lines < 1.8nm 3σ

27nm dense L/S



27nm iso lines



NXE:3100 performs significantly better than Alpha Demo Tool

26x33mm fields
After Process, Reticle and Shadowing correction

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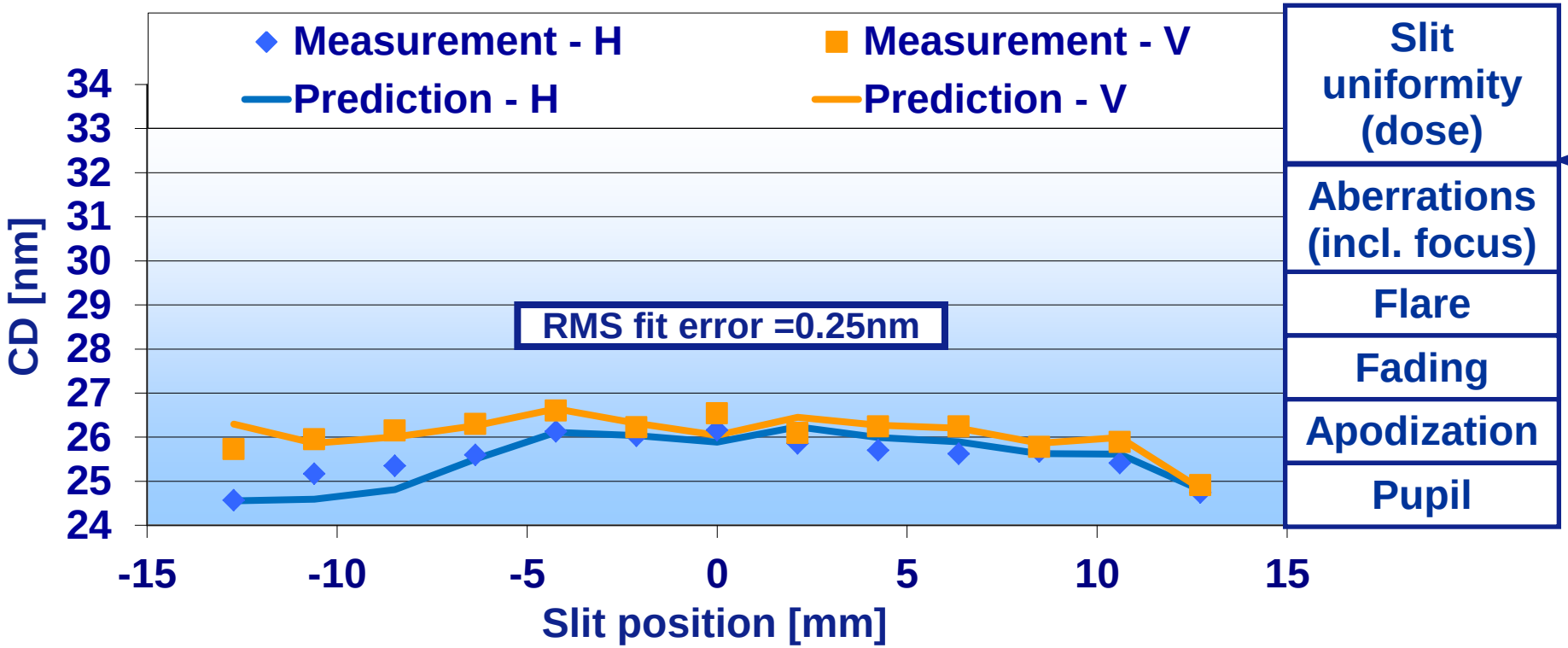
Good match between measured and predicted CD slit fingerprint 27nm isolated lines

- Predictions based on measured system data:

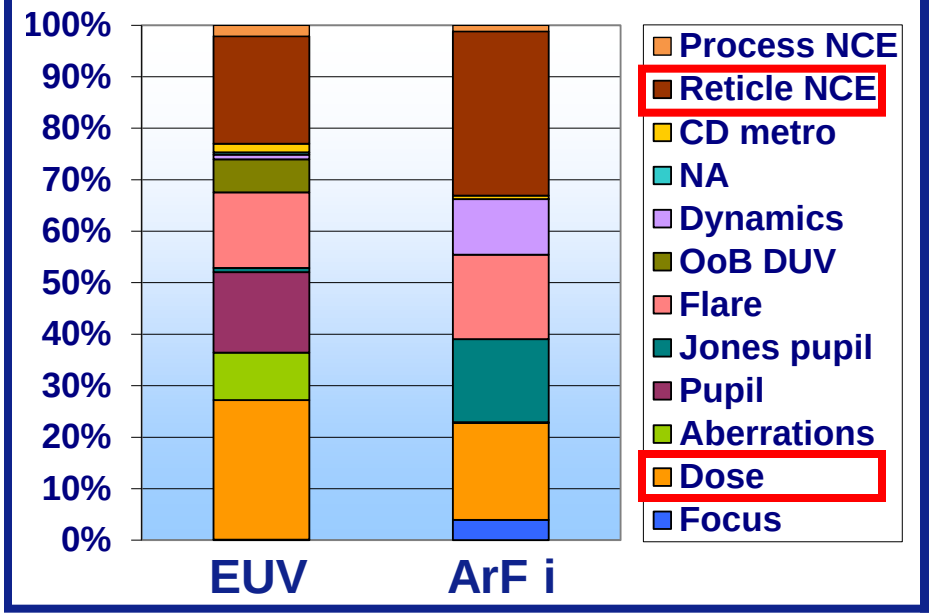


- Handshake between top-down and bottom-up budget breakdown
- Enables determination of largest contributors to CDU for roadmap purposes

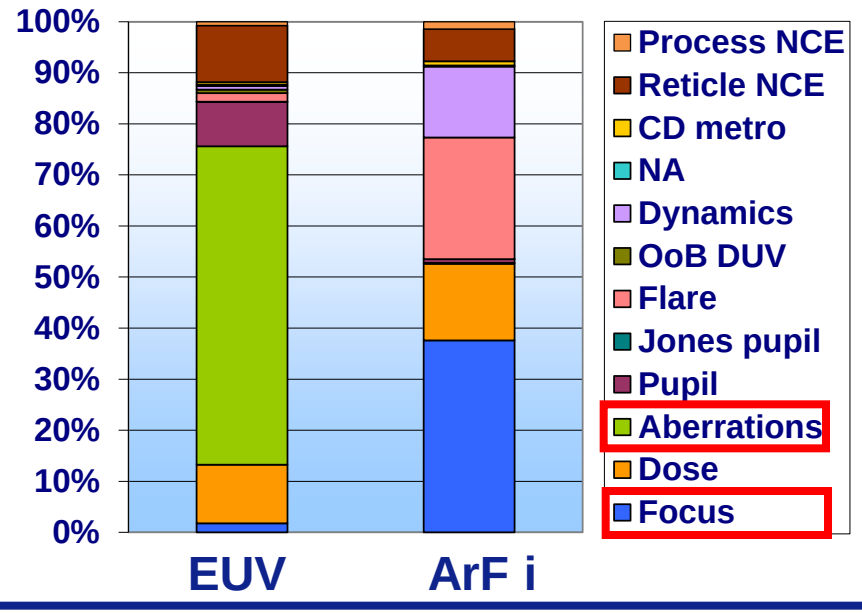
Intra field CDU budget breakdown – EUV vs ArFi:

- Similar distribution for dense L/S: Reticle and dose dominant
- Different distribution for iso lines: Aberrations vs Focus dominant

Dense L/S



Isolated Lines



EUV (27nm)	ArFi (40nm)	EUV (27nm)	ArFi (40nm)
Dose (27%)	Reticle (32%)	Aberrations (61%)	Focus (38%)
Reticle (20%)	Dose (18%)	Reticle (13%)	Flare (24%)
Illumination (16%)	Flare (16%)	Illumination (10%)	Dose (15%)

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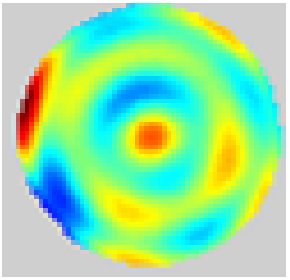
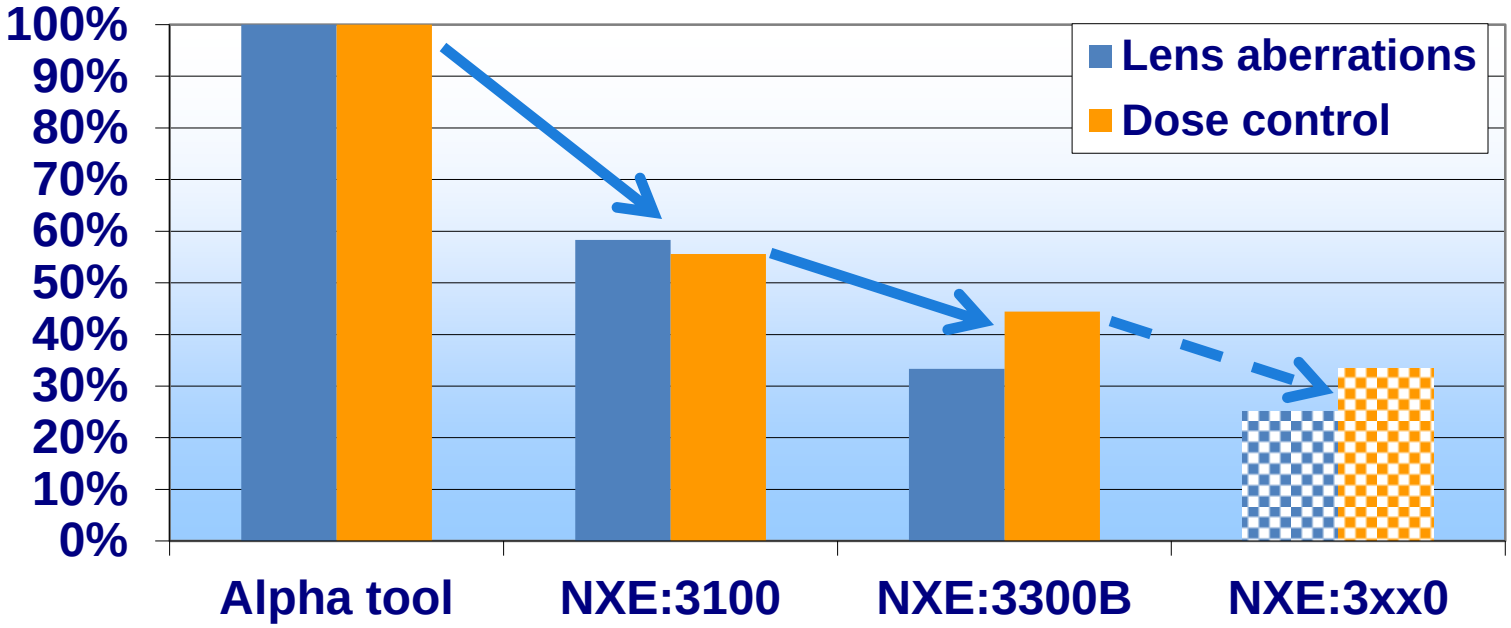
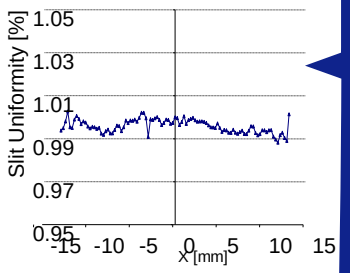
Learnings applied to NXE roadmap







- System performance roadmap from ADT to NXE:3300B shows:
  - ~3x improvement of lens aberrations
  - ~2.5x improvement of dose system performance
  - Further improvements planned for future systems

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  - **Mask contribution**
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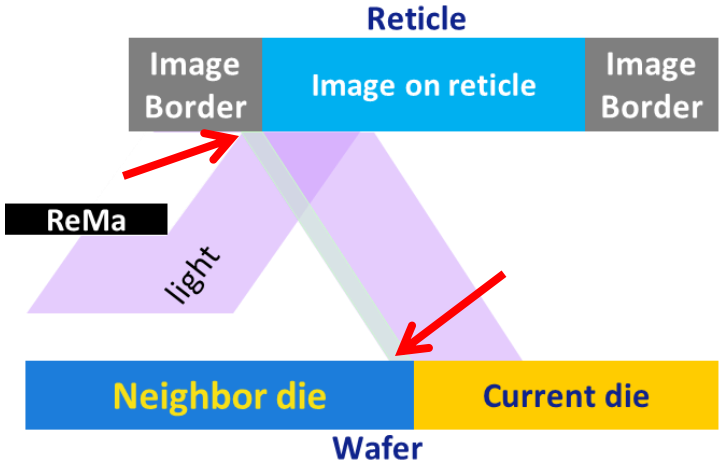
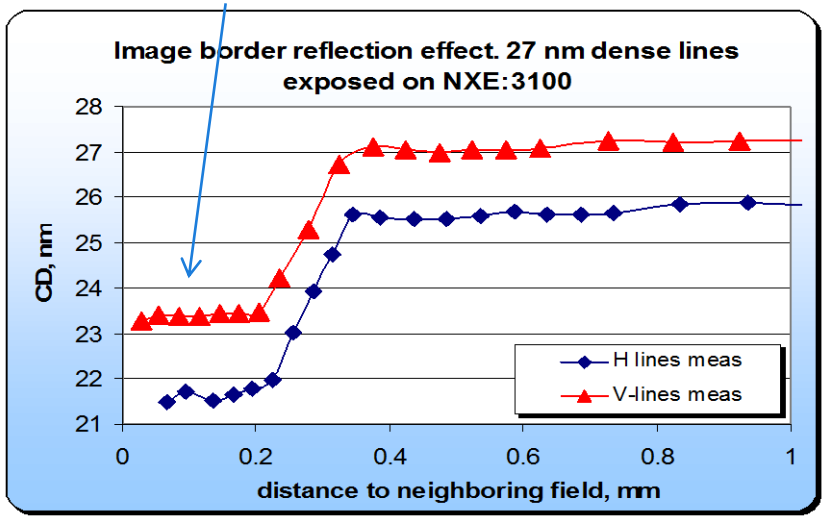
EUV reflected from image Border impacts CD neighbouring fields

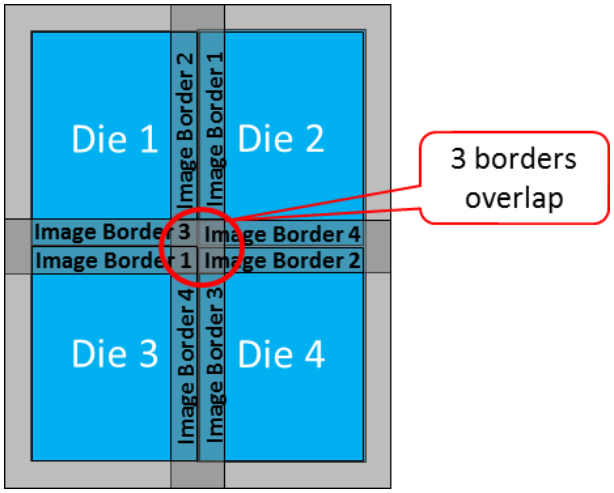
- **Image border** is a dark area around image field, free of structures (2 mm X, 3 mm Y)
- **EUV absorber - high reflectivity** (1-3%)
  - compare: ArFi mask has <0.1% transmission (OD3) in image border



4-5 nm CD drop

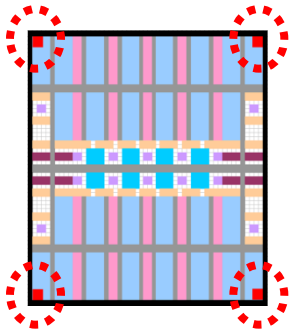


N.Davydova et al., SPIE Photomask 2011



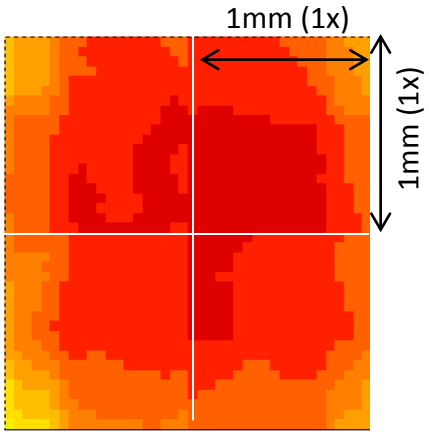
Etched ML as black border gives large reduction in CD drop at field edge and corner

Average field = All neighbors – Isolated

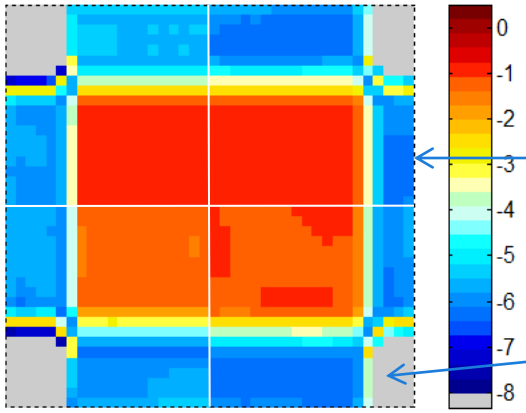


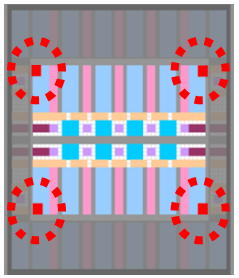
CD drop in the corner ~ 2 nm

Full Field ML etched Black Border



Small Field 55 nm absorber Image Border





CD drop at the edge ~ 5 nm

No imaging in the corners

CDU [nm]	1.1	8.6
CD range [nm]	2.3	> 10

- Big improvement (~5x) for the field with ML etched border

See poster Robert de Kruif (ASML), "Impact of an etched mask black border on imaging performance"

TOPPAN

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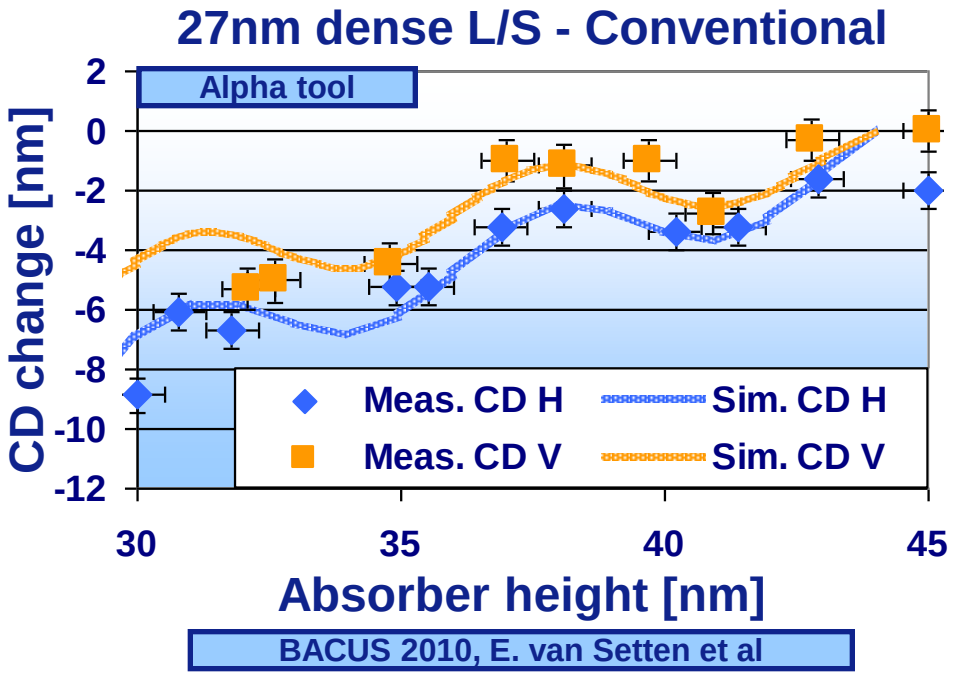
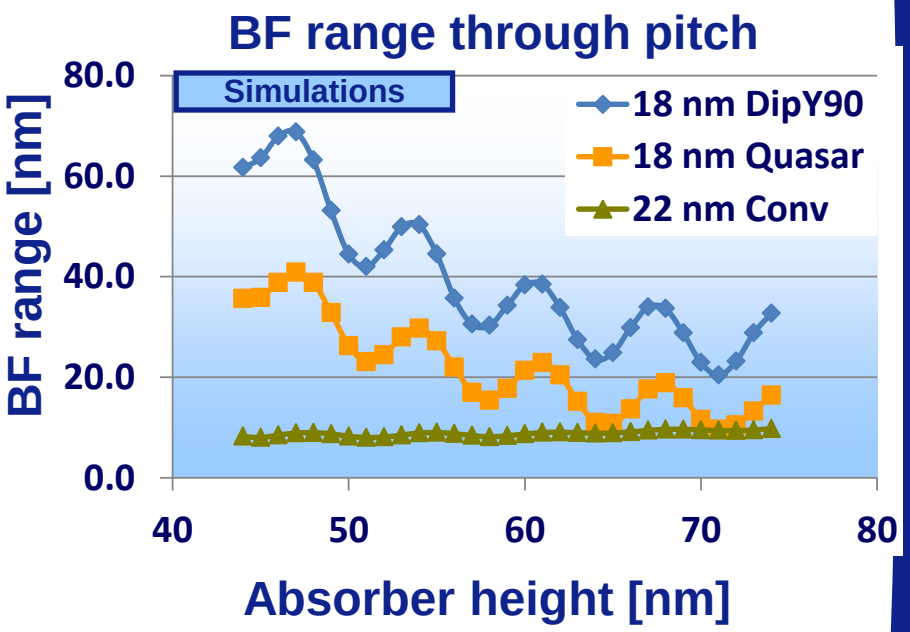
Swing behavior of CD and BF through absorber thickness





- Overlapping DoF for multiple pitches can be maximized by choosing the best absorber stack height
- => commonly used absorber height of 70nm seems OK

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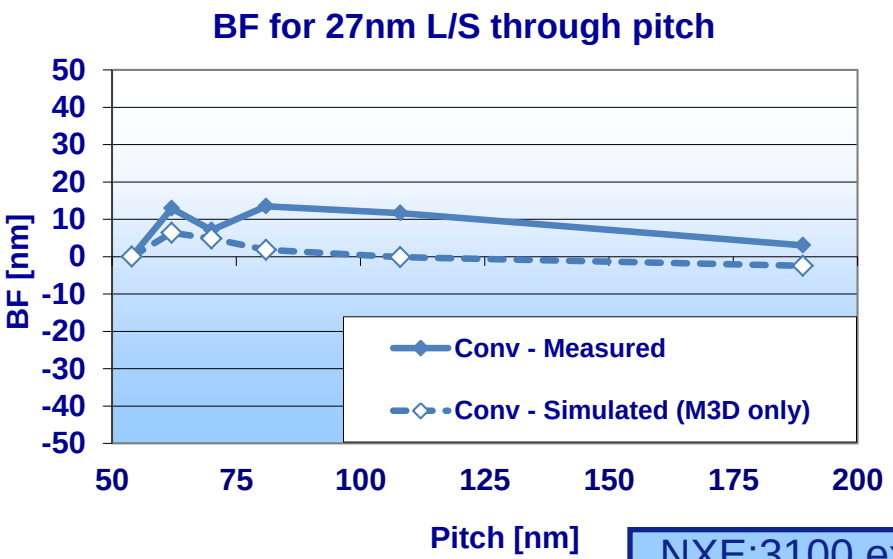
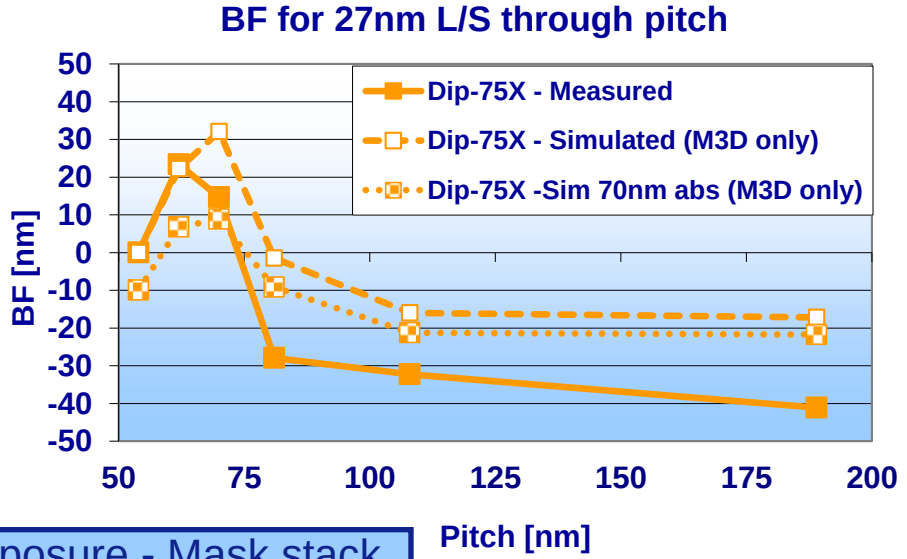
Mask induced BF variations through pitch are illumination setting dependent





NXE:3100 exposure - Mask stack with 55nm absorber

- Mask 3D induced BF variations through pitch:

27nm L/S through pitch	Measured	Simulated (M3D only)
Conventional	13nm	9nm
Dipole-75-X	64nm	49nm
Dipole-75-X (70nm abs stack)	-	31nm

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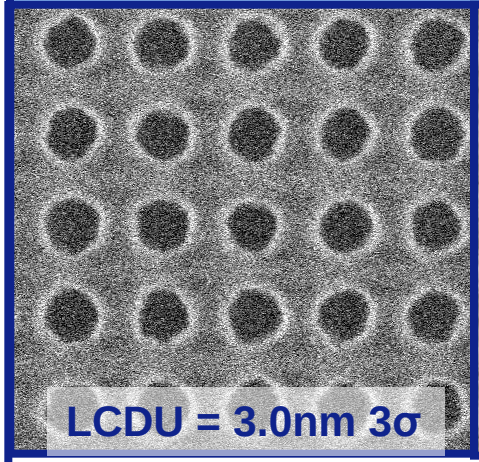
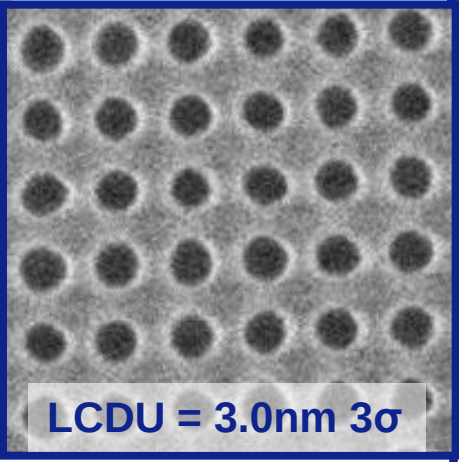
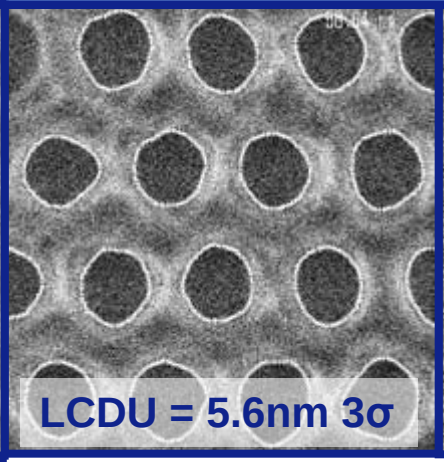
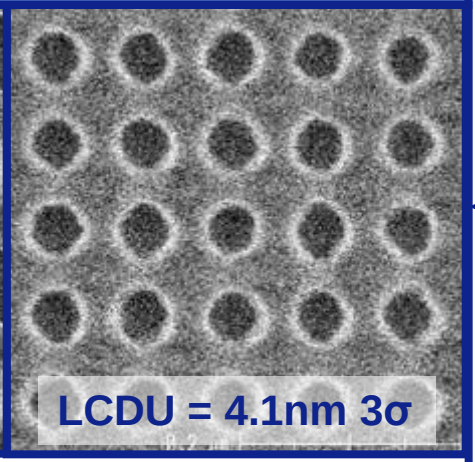
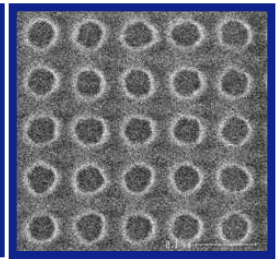
Dense CH imaging down to 26nm HP on NXE:3100
Control of local CD variations main challenge

EUV NXE:3100 | NA=0.25		ArF NXT:1950i | NA=1.35	
 LCDU = 3.0nm 3σ	 LCDU = 3.0nm 3σ	 LCDU = 5.6nm 3σ	 LCDU = 4.1nm 3σ
40nm dense CHs Single Exposure (Conventional)	26nm dense CHs Single Exposure (Quasar) imec	55nm dense CHs Single Exposure (Quasar) Positive tone developer	40nm dense CHs Double Dipole Exposure Negative tone developer

Local CDU = 3σ inside the array of 25 holes, mean across the wafer



- For sub-30nm CHs the main focus will shift to local CD variation impacting device performance

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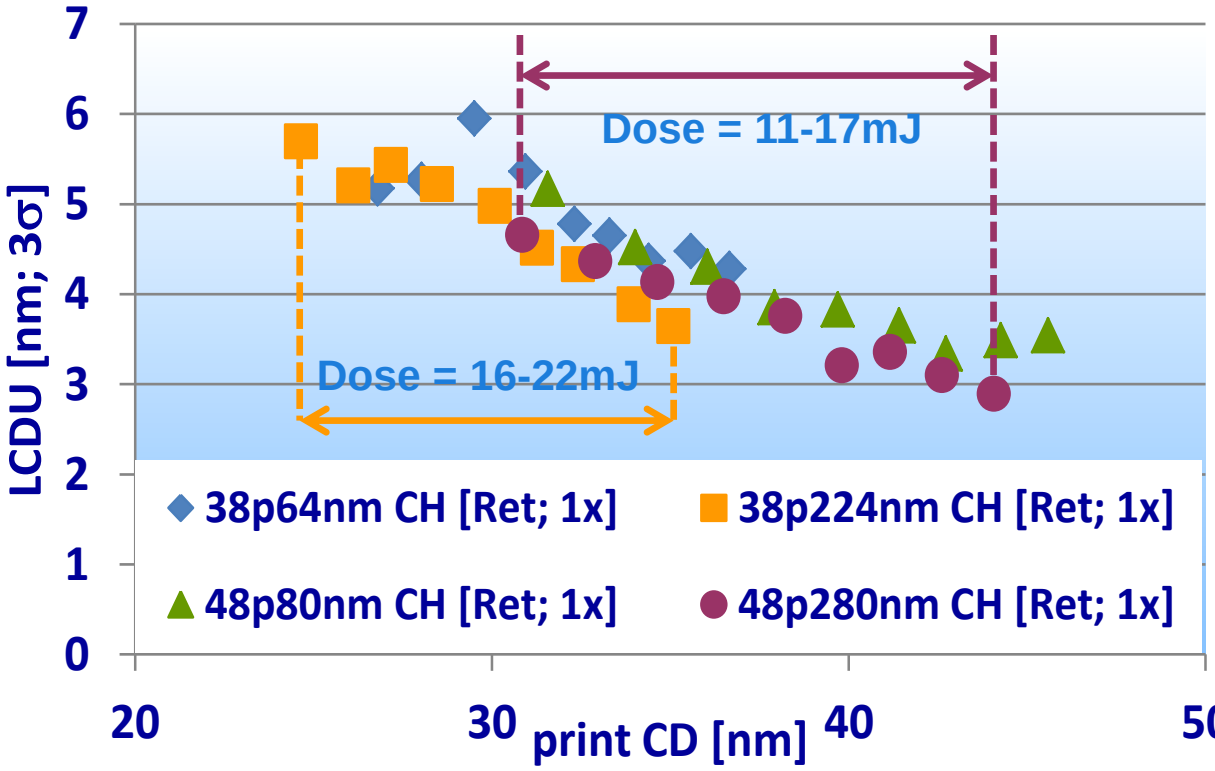
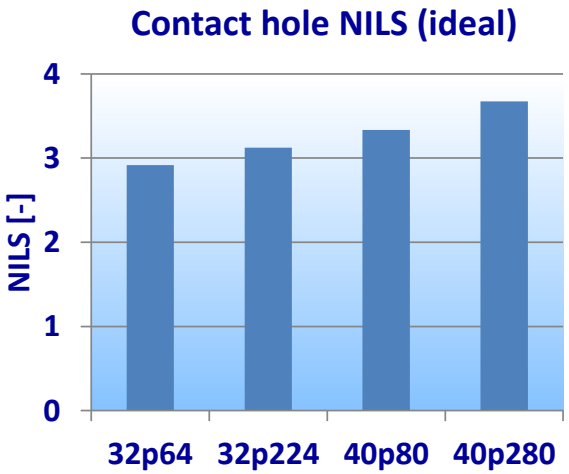
Print-bias gives significant reduction of Local CDU





- Difference between dense and iso CHs can be explained by NILS

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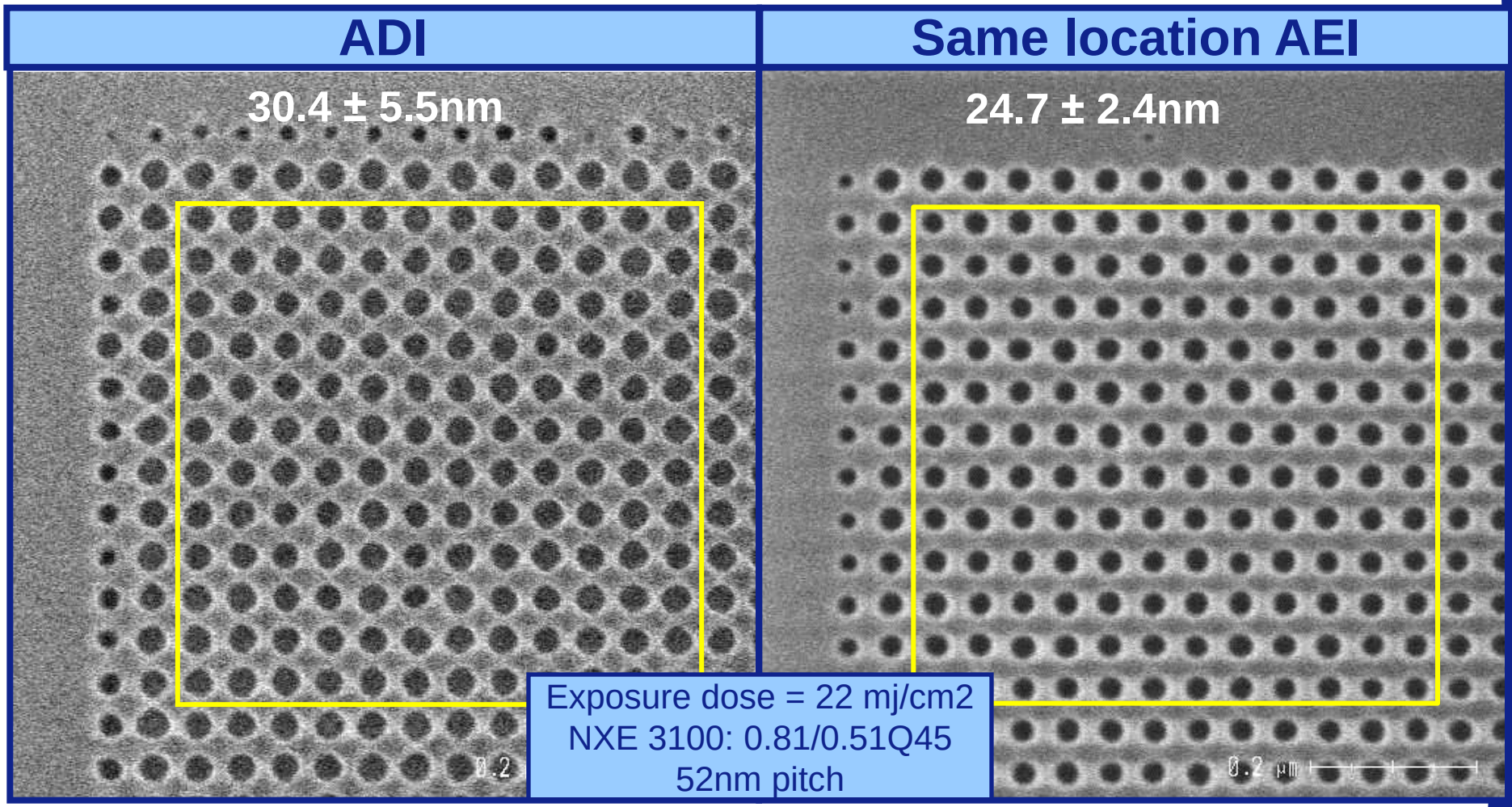
LCDU after etch leading for device performance - 2x reduction can be obtained compared to litho



Courtesy of SK hynix

SEM micrographs from the same location on wafer!

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- **NXE:3300B – Early integration results**

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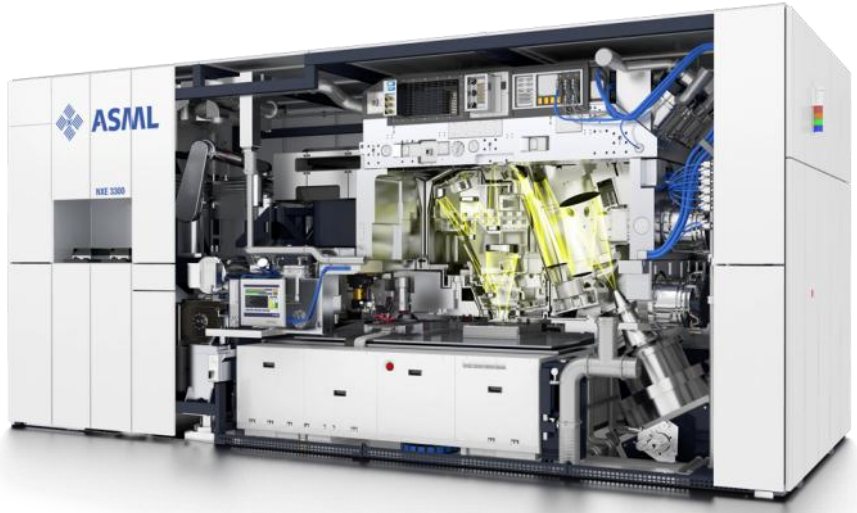
NXE platform improving with NXE:3300B system

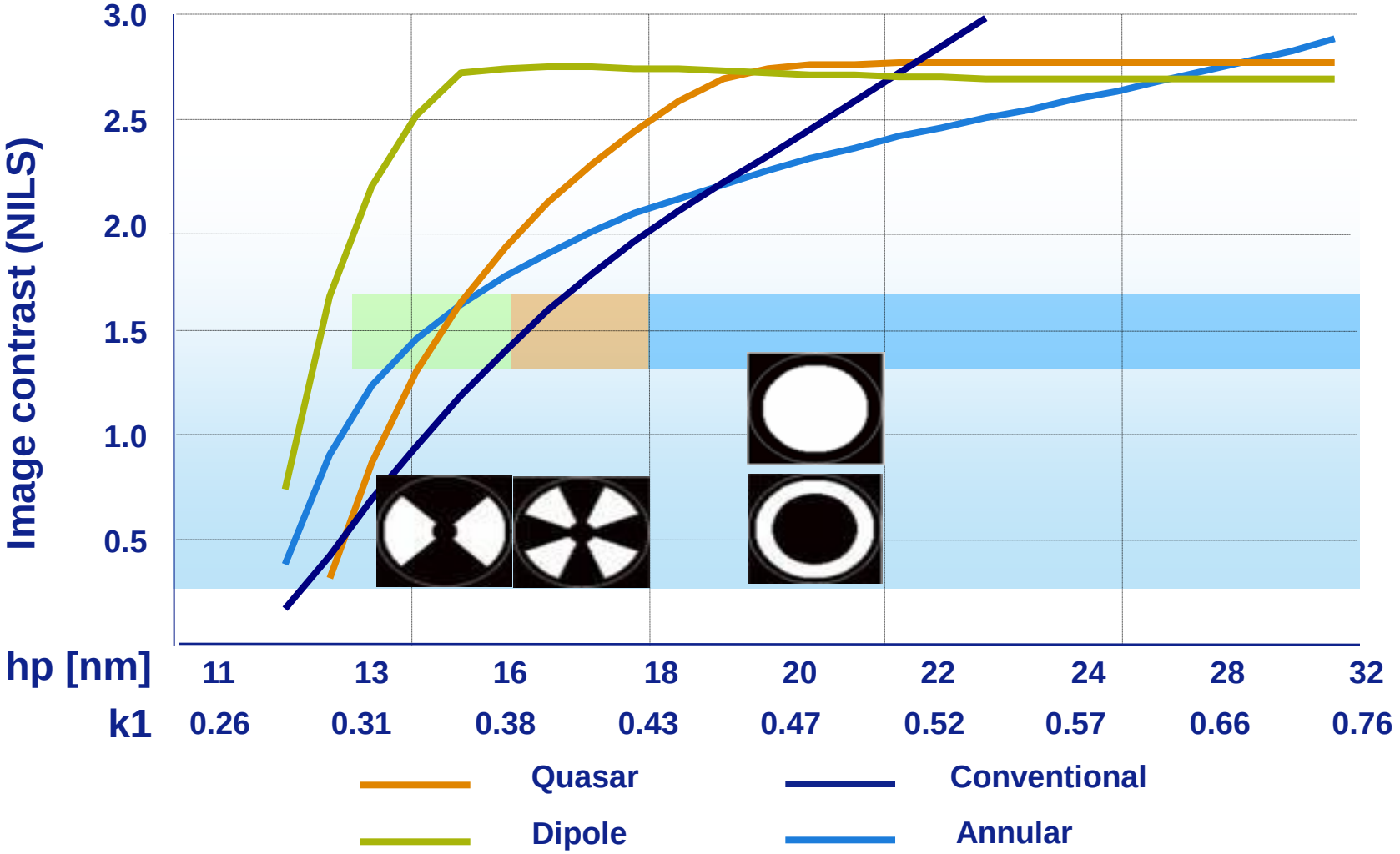
- Extends the NXE platform re-using multiple 3100 modules (stages, handlers, sensors, electronics)
- Improved optical column and a reduced footprint:
  - 0.33 NA for improved resolution
  - Increased transmission for higher productivity
  - Standard off-axis illumination capability



NXE:3300B

See presentation Stuart Young (ASML), “From R&D to High Volume Manufacturing”

Further resolution NXE:3300B extension with off-axis illumination without light loss resolution extension below 16 nm



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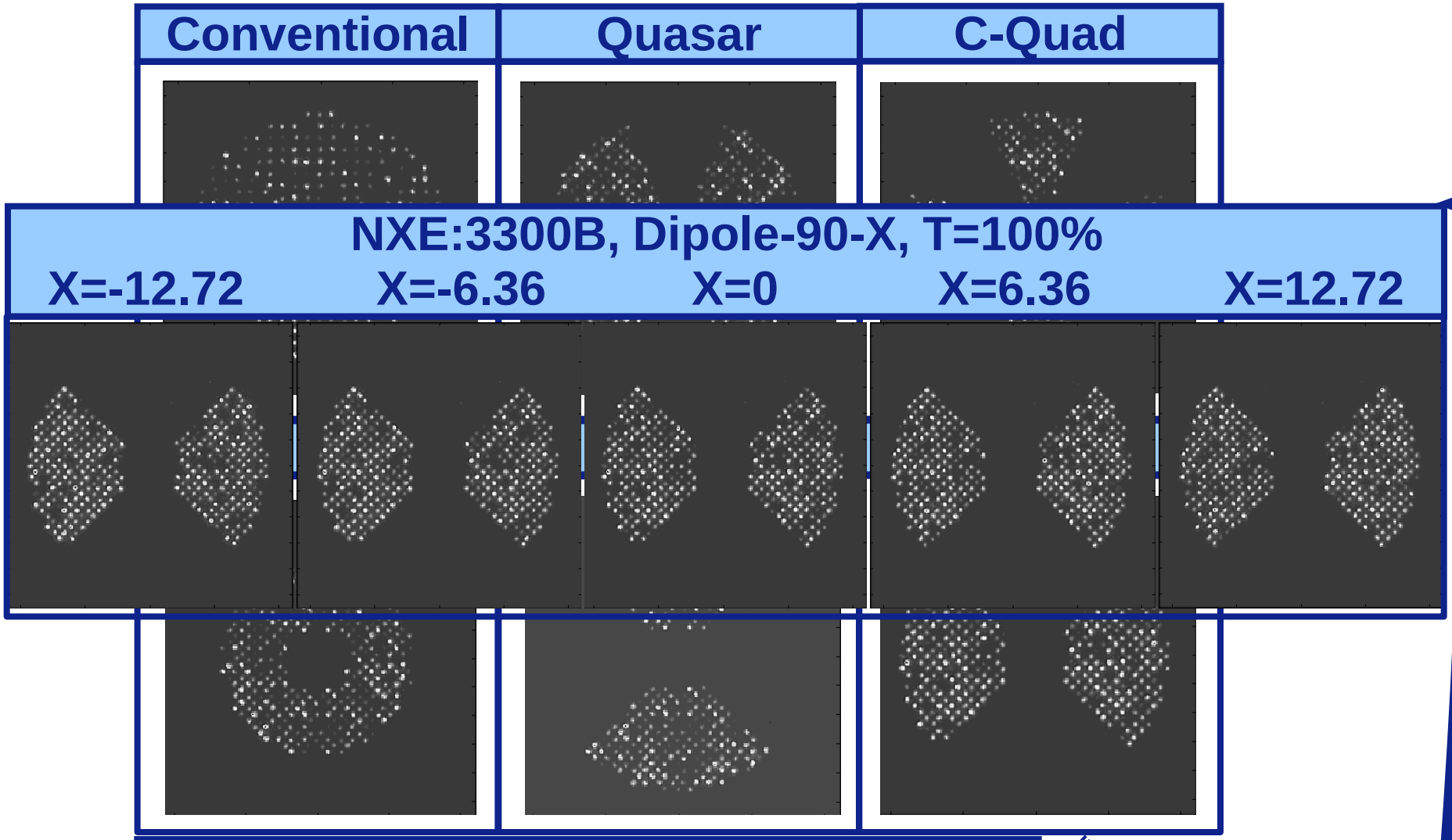
Flex illuminator fully functional on proto system: High transmission OAI demonstrated



NOTE: Early integration results => No optimization done yet

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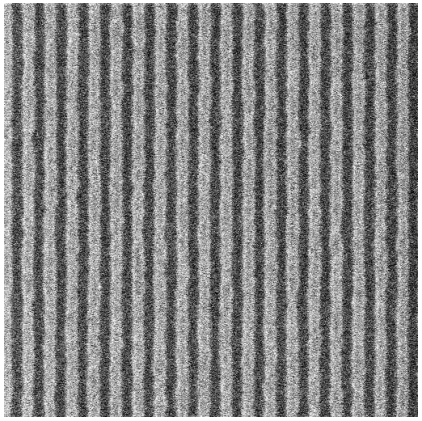
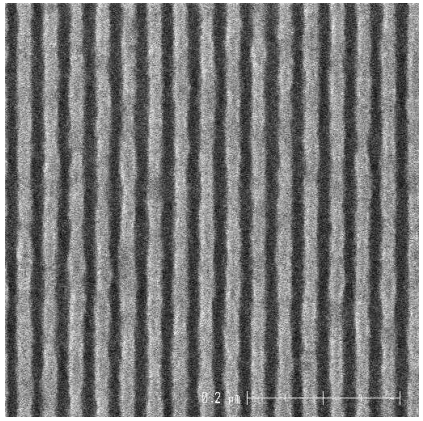
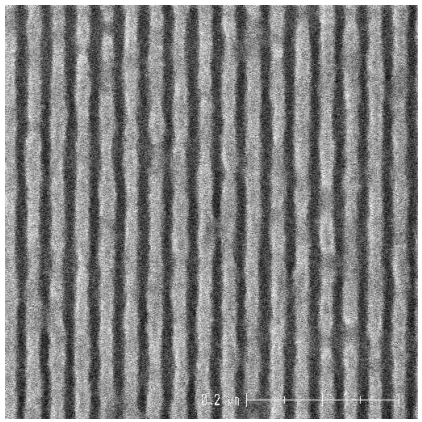
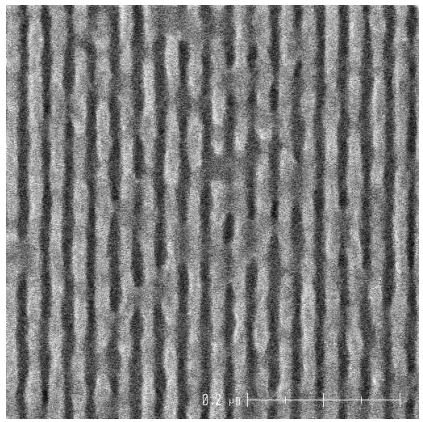
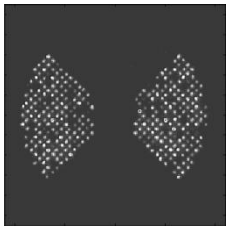
17nm HP resolution achieved on proto system with Dipole-90 illumination

18nm HP	17nm HP	16nm HP	15nm HP
			

- 17nm HP resolution demonstrated during early integration exposure
- Modulation at 15nm HP (below theoretical limit NXE:3100)
- System and process optimization ongoing



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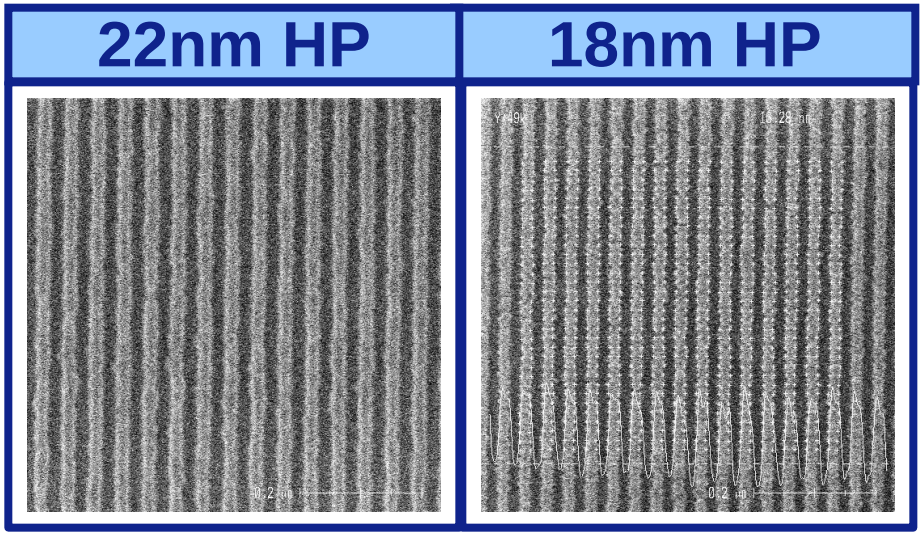
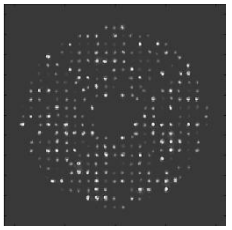
Work in progress… 18nm HP L/S resolved using conventional illumination





- 18nm HP resolution using conventional illumination after contrast improvement
- Exposures with off-axis illumination currently ongoing…

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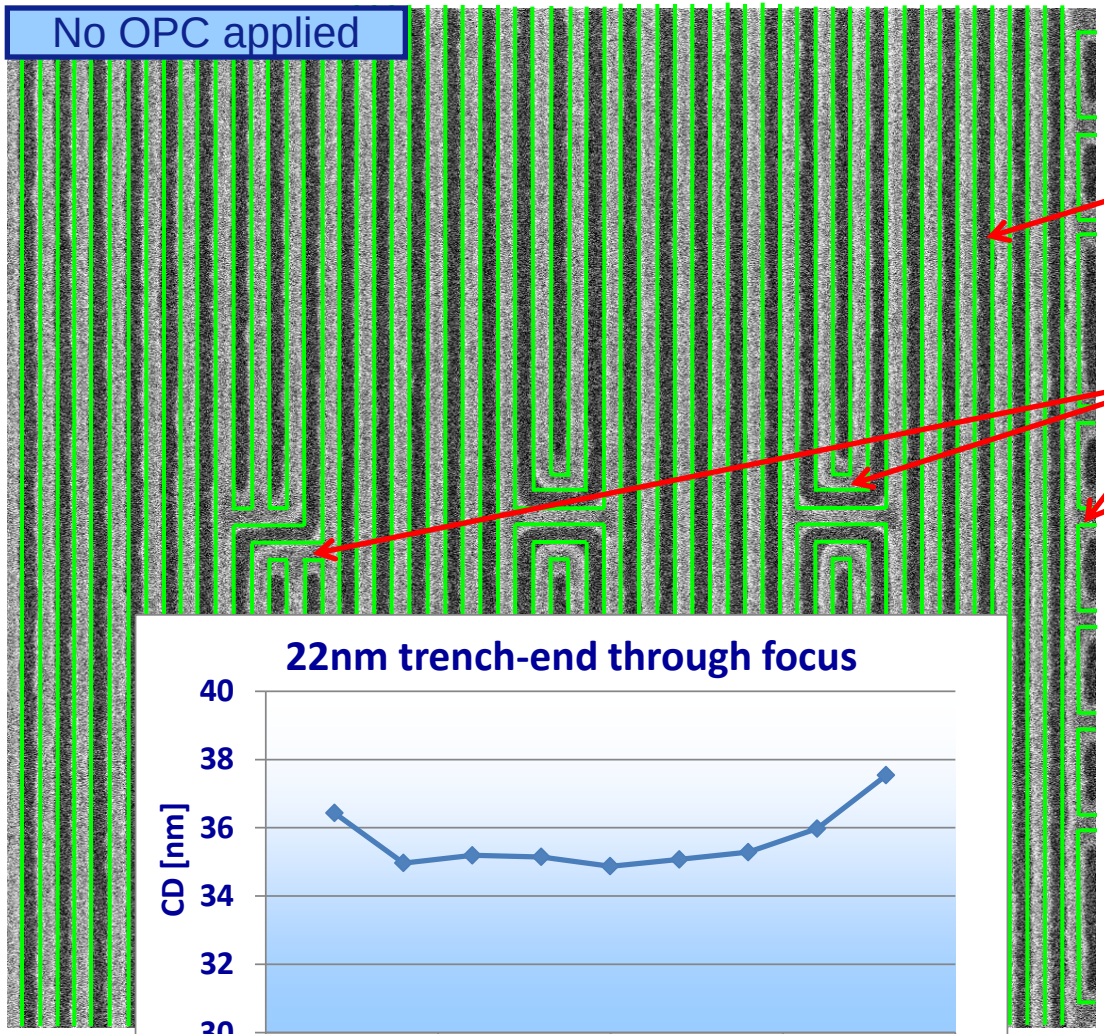
14nm node Logic Metal routing features – 44nm min. pitch and 22nm tip-2-tip



22nm trench, 44nm pitch

22nm 'tip-2-tip' (design)

- 10-15nm pull-back observed
- Flat response through focus, DoF ~ 130nm

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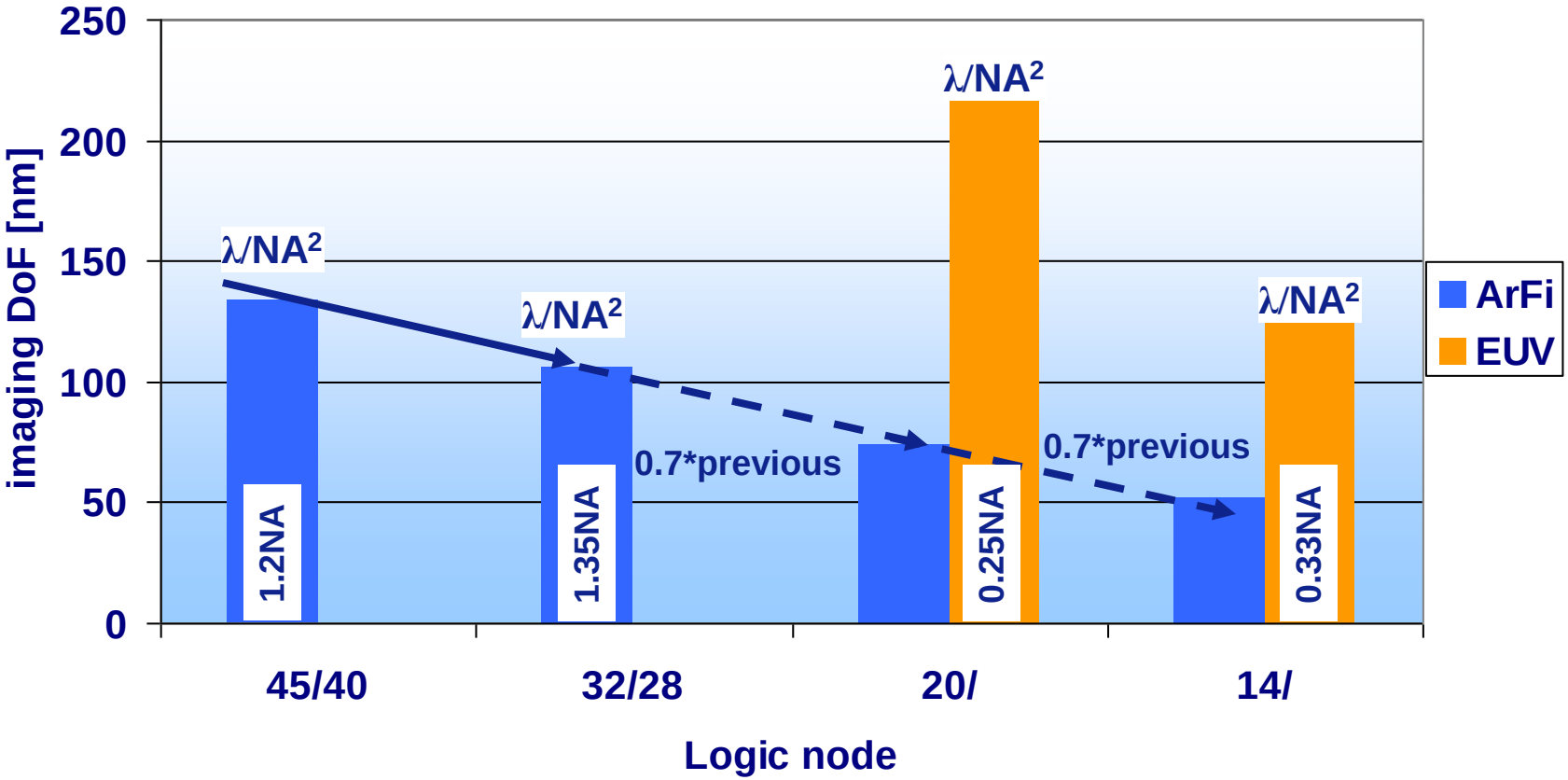
Logic CH/metal: Imaging DoF is a crucial differentiator



- Getting the best DoF (overlapping process window) and Focus control are crucial for ArF immersion
- EUV gives large enhancement of process margin

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Summary and conclusions – Getting to know the secrets of EUVL

- **The NXE:3100 provides important learning about EUVL for future systems and roadmap**
  - CDU budget understood, learnings incorporated in system roadmap
- **Good understanding of mask contribution and improvements**
  - Etched ML as image border removes CD impact at field edge and corner
  - Absorber stack can be optimized for CD and BF variations
- **Print bias and etch can give large Local CDU improvement**
- **Promising first imaging results obtained on NXE:3300B in Veldhoven:**
  - High transmission Flex-illuminator fully functional
  - 14nm node random logic with ~130nm DoF

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Acknowledgements

- The work presented today, is the result of hard work and dedication of teams at ASML and many technology partners worldwide including our customers
- Special thanks to:
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Thank you for your attention!